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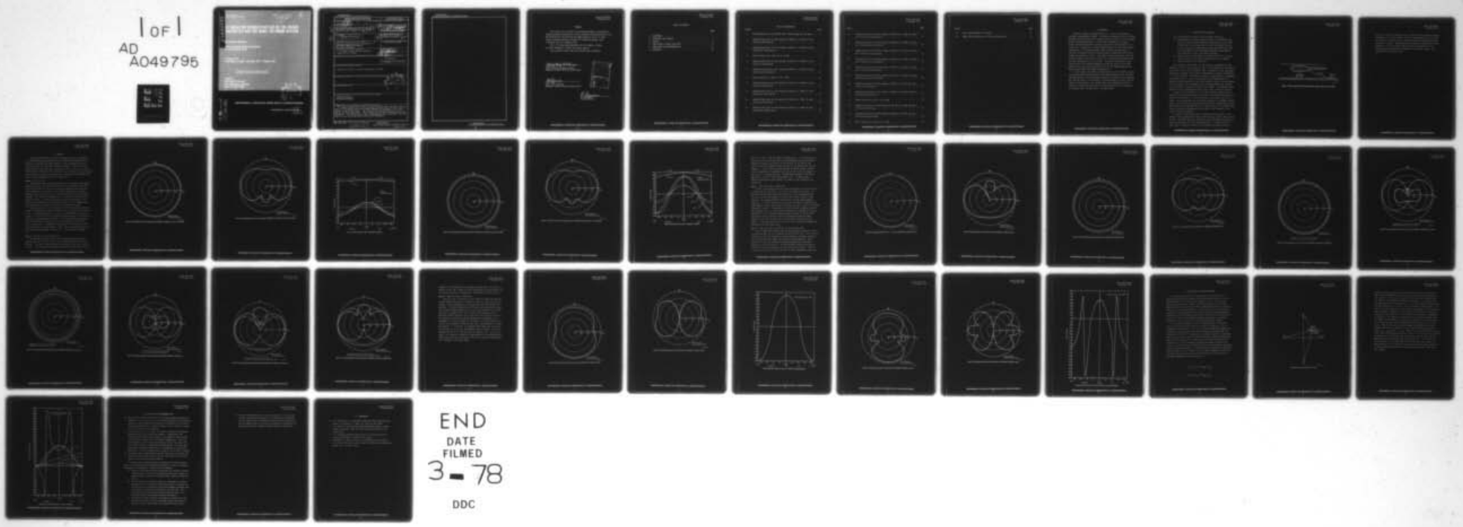

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HF RADIATION CHARACTERISTICS OF THE RH-53D HELICOPTER AND THE MARK 105 AMCM SYSTEM

L.N. Medgyesi-Mitschang

McDonnell Douglas Research Laboratories
St. Louis, Missouri 63166

1 February 1977
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A computer algorithm is used to predict the power gain and phase characteristics of the Raydist receiving antenna (modified retractable hf type) used aboard the RH-53D helicopter. The calculations were performed at 1.6 and 3.3 MHz for the horizontal plane. Both vertical and horizontal polarizations were considered. Four different tow cable configurations were investigated and their effect on the receiving antenna system were determined.

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PREFACE

This report is an account of the work performed at the McDonnell Douglas Research Laboratories on the hf Radiation Characteristics of the RH-53D Helicopter and the Mark 105 AMCM System for the U. S. Naval Coastal Systems Laboratory, Contract No. N61331-76-M-4839, from 1 November 1976 to 1 February 1977.

Mr. J. M. Putnam was responsible for the computer coding. Mr. Paul Eisenhauer, of NCSL was project monitor.

This technical report has been reviewed and is approved.

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1. BACKGROUND

Accurate, updated navigational data is a critical requirement in anti-mine countermeasures (AMCM). The Raydist navigation system (Teledyne Hastings) provides such data by referencing the aircraft or vessel engaged in mine sweeping operations to fixed Raydist transmitter locations. Using a patented heterodyne technique, the Raydist system provides continuous phase comparison of signals emanating from the stationary Raydist transmitters. For proper operation these reference signals must be received continuously without anomalous phase or amplitude fluctuations aboard the aircraft or vessel. The signal levels received are functions of many parameters such as the location of the Raydist receiving antenna and the configuration of the aircraft. The mutual interaction of the aircraft skin, the receiving antenna, and the tow cable for the AMCM platform can cause severe distortions in both the signal magnitude and phase received from the Raydist transmitters.

In this report, the radiation characteristics of the Raydist antenna system aboard the RH-53D helicopter are examined together with the Mark 105 AMCM platform. Using predictive computer techniques the re-radiation and coupling effects of the Raydist receiving antenna, aircraft, and tow cable are incorporated. The results from this investigation will be used as a baseline and bench mark to treat analytically, and ultimately to optimize, other systems used in the AMCM effort.

2. OBJECTIVES AND APPROACH

This investigation focused on the following objectives:

a) development of a suitable computer model for the RH-53D helicopter to predict the hf radiation characteristics at 1.6 and 3.3 MHz both in free-space and in a hover mode above the sea. In this analysis, the radiation patterns are computed for the prototype Raydist receiving antenna (modified retractable hf type) presently in use on the RH-53D aircraft.

b) extension of the above model to include the effects of the tow cable attached to the Mark 105 AMCM platform, at a nominal flight altitude of 30 m (100 ft).

The technique used by MDRL for this study is an extension of the analysis described in References 1-3 for hf loop radiators on helicopters and relies on the method of moments (MM). A synopsis of this technique, particularly germane to the present investigation, is given in Reference 4. In this technique, the vehicle fuselage is represented by a segmented conducting surface. A typical helicopter can be approximated by a perfectly conducting body of revolution, having a surface area equivalent to the original vehicle fuselage. The receiving antenna and tow cable can be attached at arbitrary locations on the body. An idealized representation of the configuration used in this study is shown in Figure 1.

As described in Reference 2, the entire radiation problem can be treated as an equivalent network system, with the unknowns being the currents on the surface of the body (fuselage), the antenna, and the tow cable. In this analysis, the interactions between the fuselage, antenna, and tow cable are in an analytically amenable form, permitting the phase distortion and re-radiation effects of various parts of the configuration (such as helicopter appendages and tow cable) to be included in the overall radiation patterns.

A computer algorithm was used to determine the power gain of the Raydist (whip) antenna aboard the aircraft with and without the tow cable present. The power gain was calculated in the horizontal (yaw) plane in both the horizontal and vertical polarizations. In addition to the power gain, the phase variation of the Raydist receiving system as a

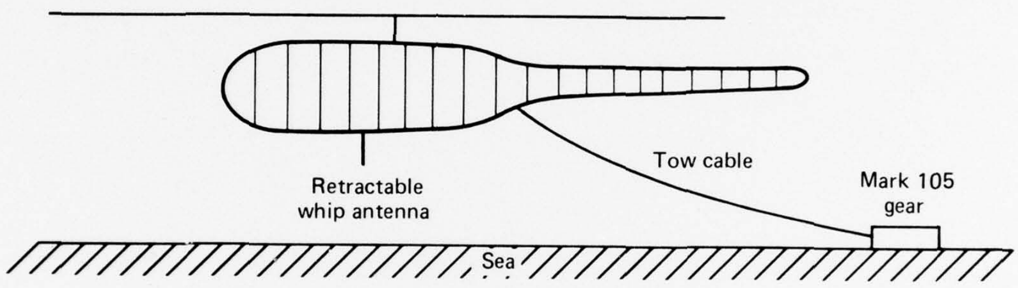

Figure 1 MM representation of helicopter with a whip antenna and tow cable

function of azimuthal angle was also calculated at the principal Raydist frequencies of 1.6 and 3.3 MHz. Since the navigational data in the Raydist system is obtained from the phase differences measured aboard the aircraft of signals emanating from the stationary transmitters, phase variations of the receiving antenna system are important and can affect adversely the proper functioning of the Raydist system. This problem will be discussed later.

3. RESULTS

Five different antenna-tow cable configurations were investigated for the RH-53D aircraft modeling various conditions encountered in the operation of the Mark 105 AMCM platform. These configurations were: 1) no tow cable, 2) vertically extended tow cable, 3) short tow cable trailed aft, 4) short tow cable trailed aft 20 deg. to port side, and 5) long tow cable trailed aft. The radiation characteristics in the horizontal (yaw) plane for the whip antenna presently used aboard the aircraft with each of these configurations are described below.

Case 1: No tow cable.

Initially the power gain characteristics of the Raydist whip antenna mounted at Station 272 and located 48.3 cm (19 in) from the centerline on the bottom port side of the aircraft were computed without any tow cable attached to the aircraft. The antenna consisted of a 16 gauge braided wire, 136 cm (53.5 in) in length, extending vertically from the fuselage. The wire was terminated at its tip with a 50 MΩ static suppressor resistor. In these calculations an aircraft altitude of 30 m (100 ft) was assumed, and a sea conductivity of 5×10^{-3} siemans (S)/m, corresponding to a salinity of 35 parts per thousand was used.

The gain patterns for this antenna at 1.6 MHz in vertical and horizontal polarizations are shown in Figures 2 and 3, respectively, plotted in dB. The phase variation in the vertical polarization is shown in Figure 4. As can be seen the vertically polarized pattern is effectively isotropic in both magnitude and phase. In the horizontal polarization on the other hand, the gain pattern shows two distinct nulls off the tail of the aircraft. Broadside, the magnitude of the patterns in the two polarizations are approximately equal. The corresponding results at the other principal Raydist frequency of 3.3 MHz is given in Figures 5-7.

Case 2: Tow cable in vertical position.

For analysis of cable effects, the foregoing calculations were repeated for the case where the tow cable extended vertically from the aircraft. The same aircraft altitude and antenna location were used as in Case 1. The vertically and horizontally polarized patterns for this

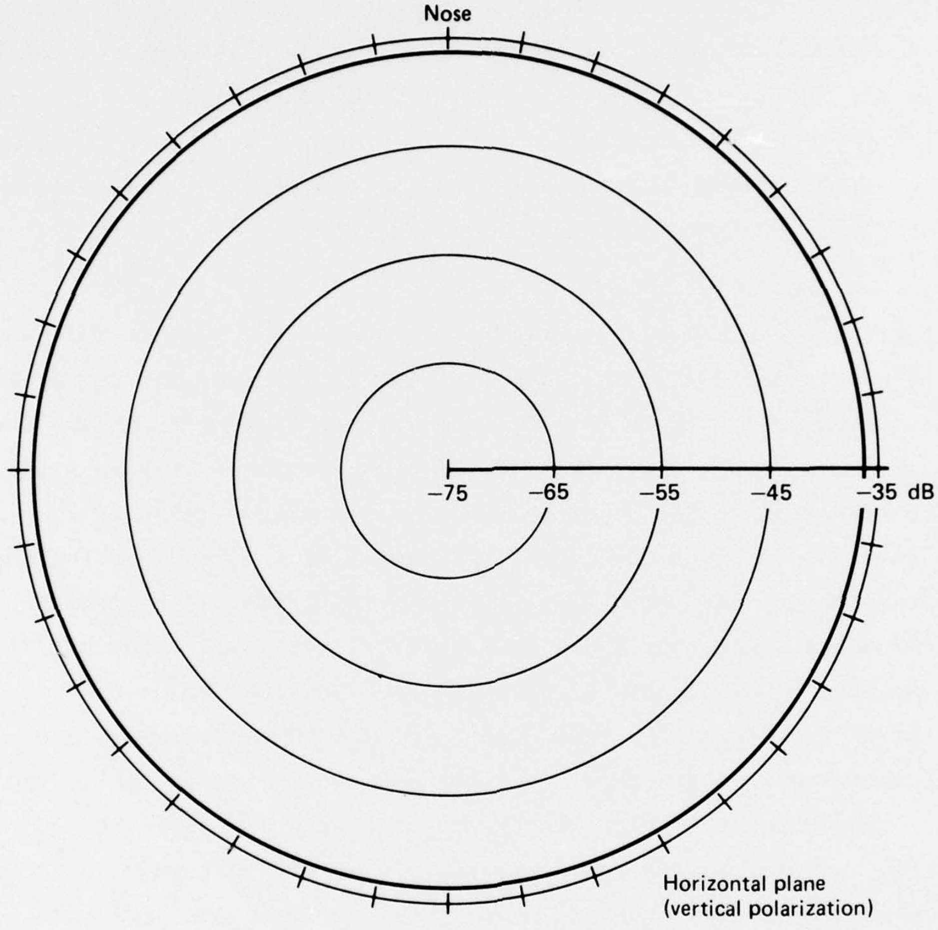

Figure 2 Computed power gain for whip antenna on RH-53D at 1.6 MHz for case 1 (no tow cable)

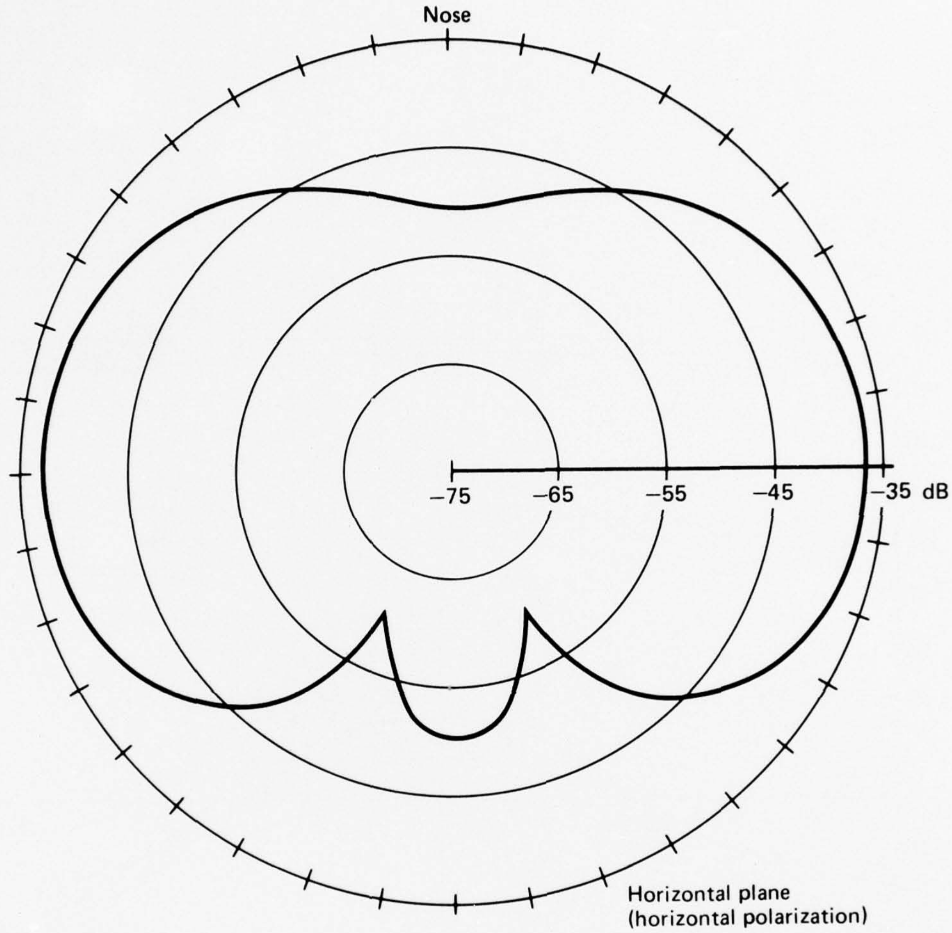

Figure 3 Computed power gain for whip antenna on RH-53D at 1.6 MHz for case 1 (no tow cable)

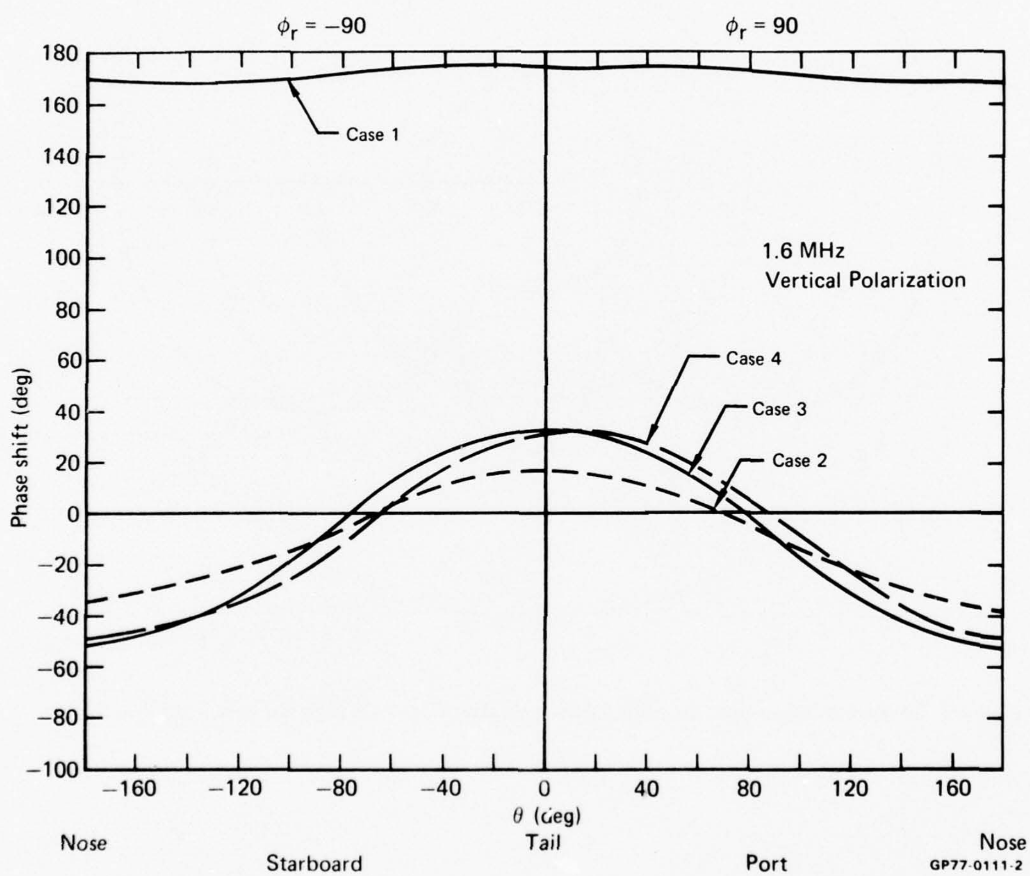

Figure 4 Phase variation for cases 1 through 4 at 1.6 MHz

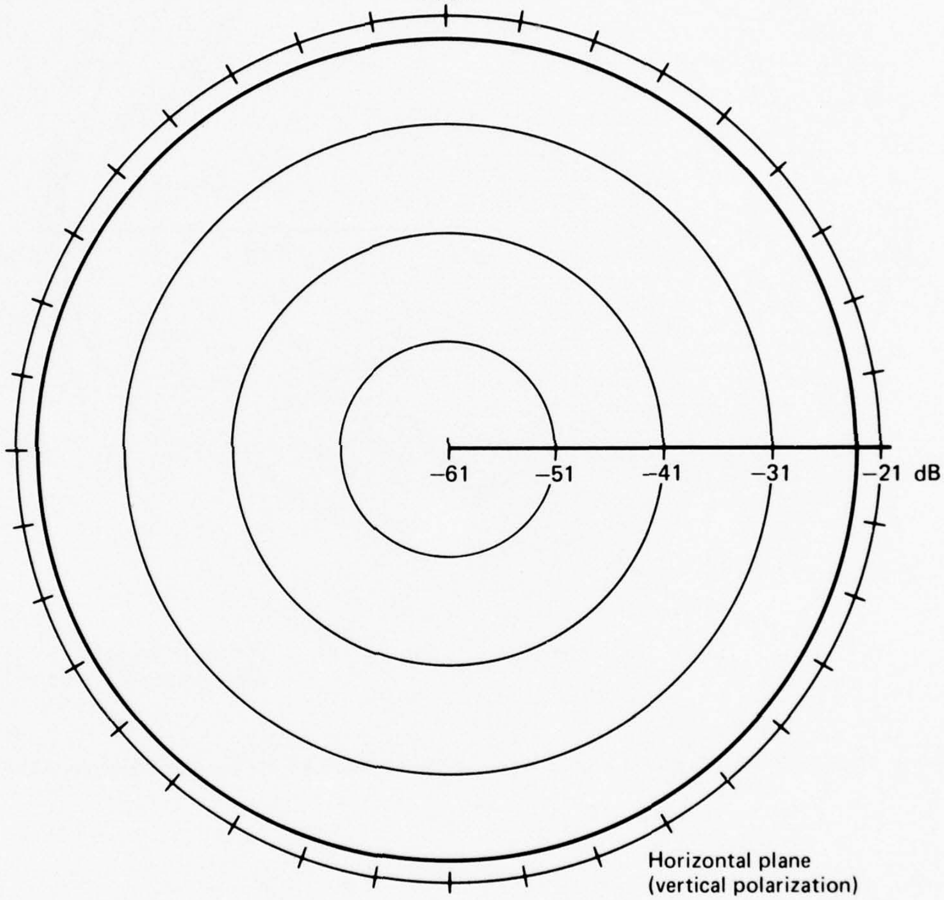

Figure 5 Computed power gain for whip antenna on RH-53D at 3.3 MHz for case 1(no tow cable)

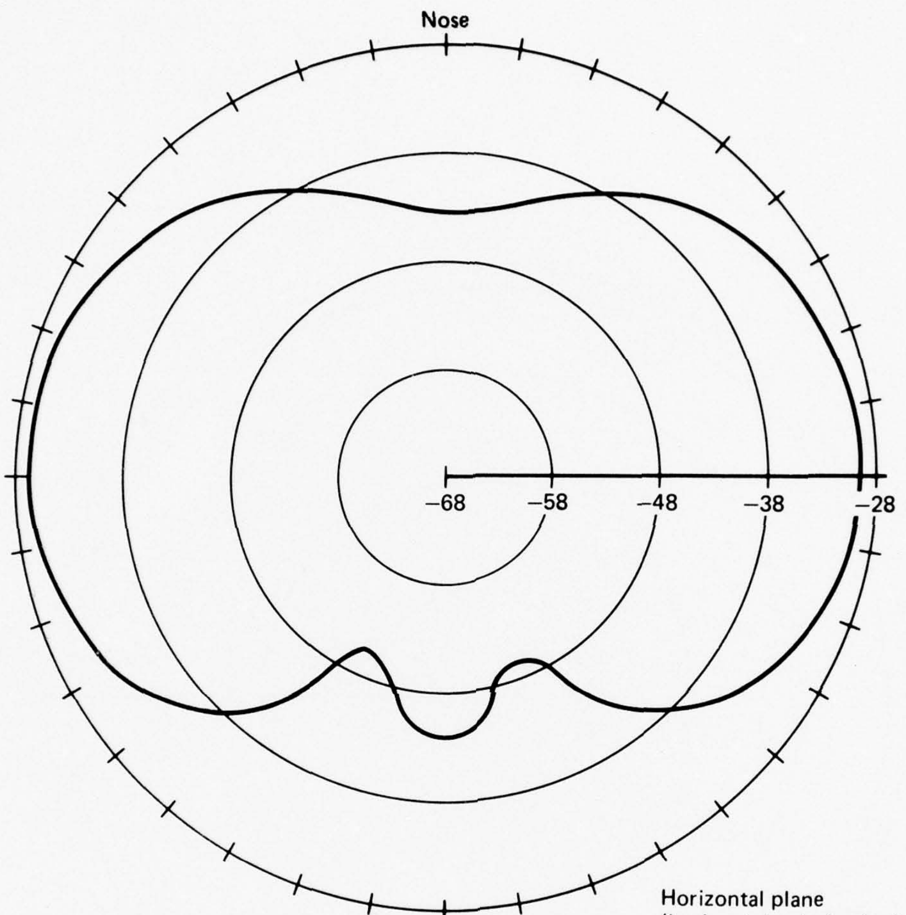

Figure 6 Computed power gain for whip antenna on RH-53D at 3.3 MHz for case 1 (no tow cable)

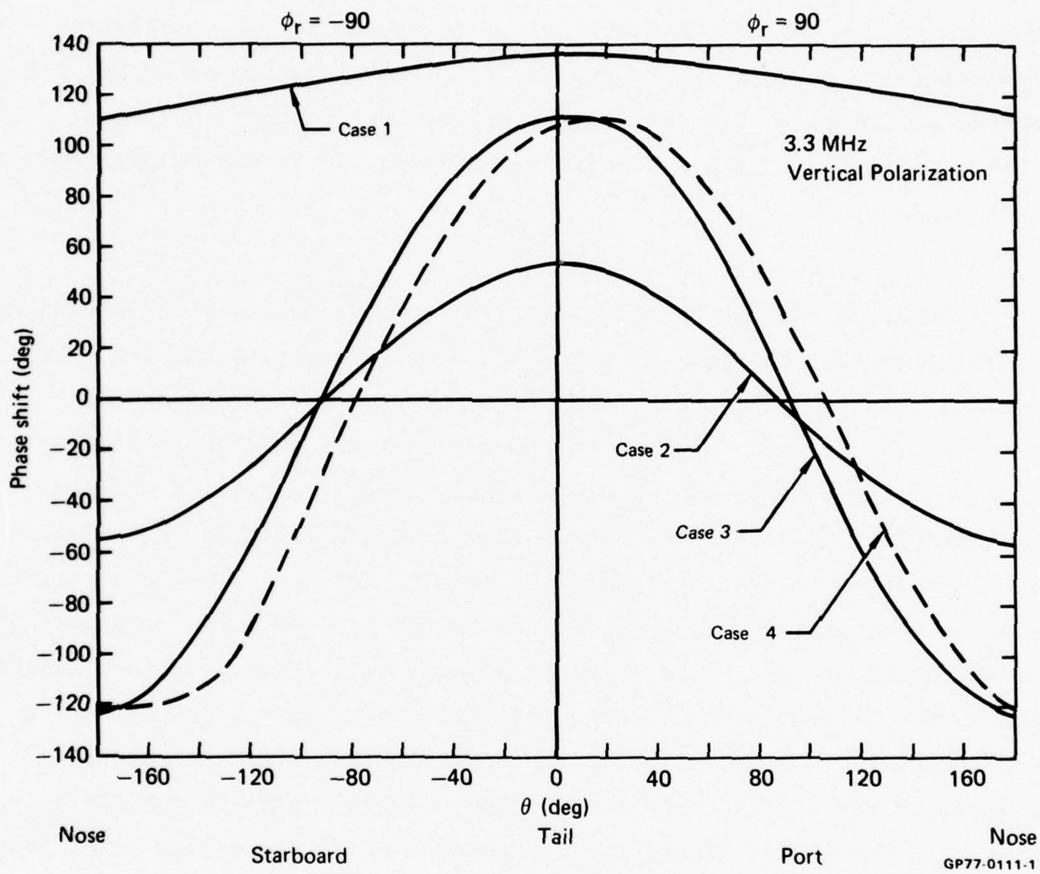

Figure 7 Phase variation for cases 1 through 4 at 3.3 MHz

case at 1.6 and 3.3 MHz are shown in Figures 8-11. It is interesting to note that in this case the nulls in the horizontally polarized pattern (Figure 9) appear to be shifted to the vicinity of the nose of the aircraft from their previous position (with no tow cable) near the tail (Figure 3). The vertical patterns (Figures 8 and 10) appear isotropic at both frequencies in magnitude only, and as can be seen in Figures 4 and 7 there is no phase isotropy. Maximum phase changes of 80 and 110 degrees at 1.6 and 3.3 MHz, respectively occur. As shown below, a similar nonisotropic phase behavior is present in the subsequent configurations.

Case 3: Short tow cable, trailed aft.

In this configuration, the tow cable was assumed to be 43 m (141 ft) in length and was trailed so as to form a 45° angle with the sea. In these calculations only weak coupling to the sea was considered since the Mark 105 tow cable appears to provide only a poor link at hf frequencies. The antenna position and aircraft altitude were unchanged from Case 2. The gain patterns for this case are given in Figures 12-15. Superimposed on these results are the results for Case 2 (with a vertically extended tow cable). As expected, the vertical cable reradiated most of the impinging energy in the vertical polarization, resulting in a slight enhancement of the vertical polarized signal (Figures 12 and 14) and a substantial (20 dB) reduction in the horizontally polarized signal (Figures 13 and 15) from the case of the obliquely trailed tow cable (Case 3). The phase variations in Figures 4 and 7 again show significant nonisotropy for the present case.

Case 4: Short tow cable, trailed aft 20 deg. to port side.

This configuration differs from the preceding one in that the cable is trailed 20 deg. off the centerline toward the port side. This case was considered to test the sensitivity of the pattern to simulate cable-aircraft orientations that might occur during turning maneuvers. Calculations show that the vertically polarized patterns are effectively identical to those for Case 3. In the horizontal polarization (Figures 16 and 17), the nulls disappear off the tail of the aircraft. This is an expected result since a null off nose or tail, presupposes centerline

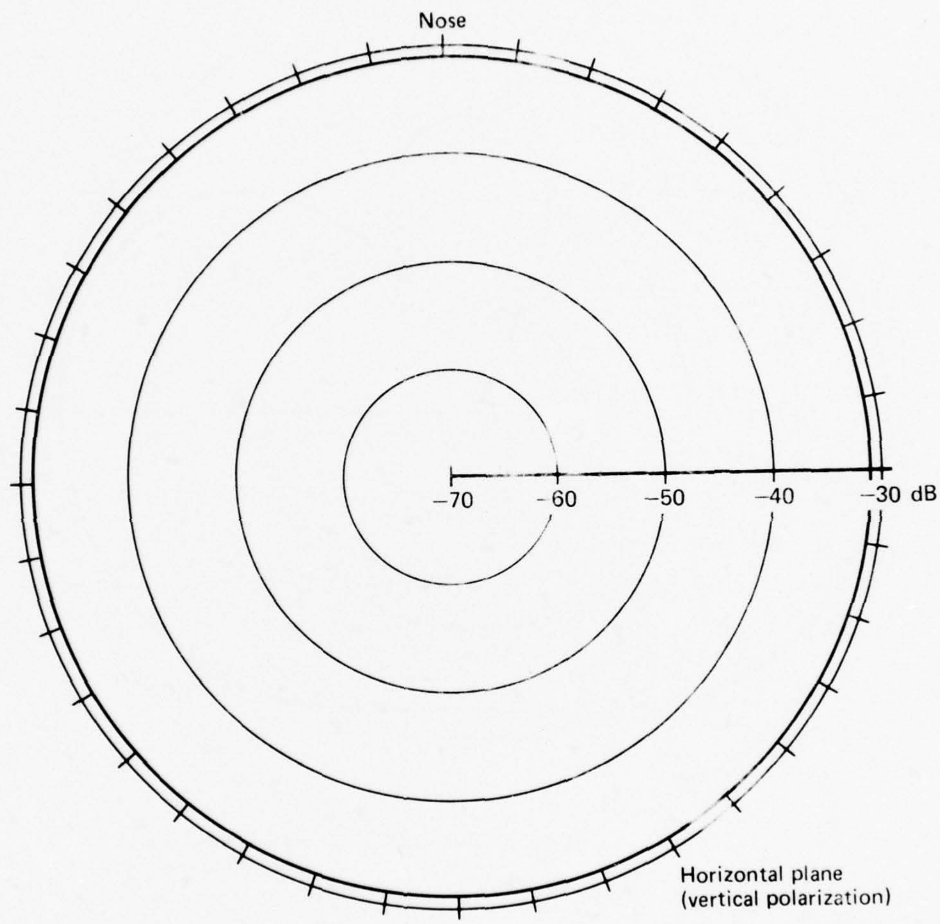

Figure 8 Computed power gain for whip antenna on RH-53D at 1.6 MHz for case 2

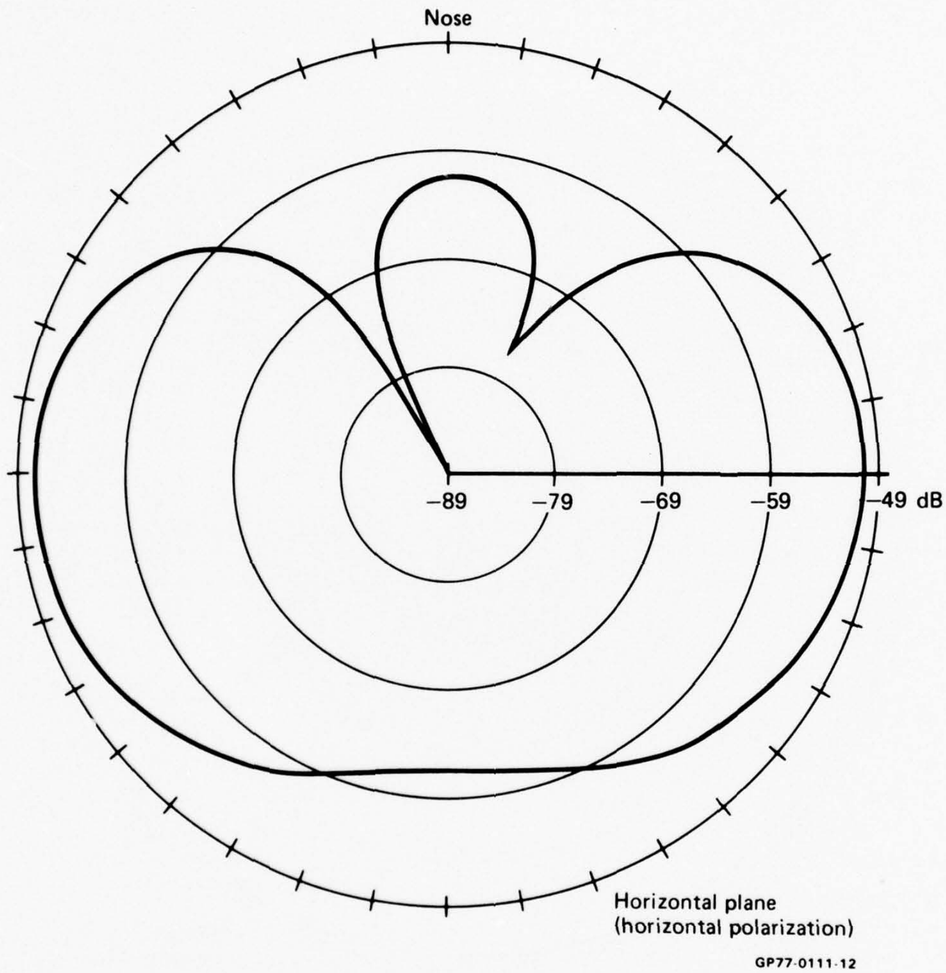

Figure 9 Computed power gain for whip antenna on RH-53D at 1.6 MHz for case 2

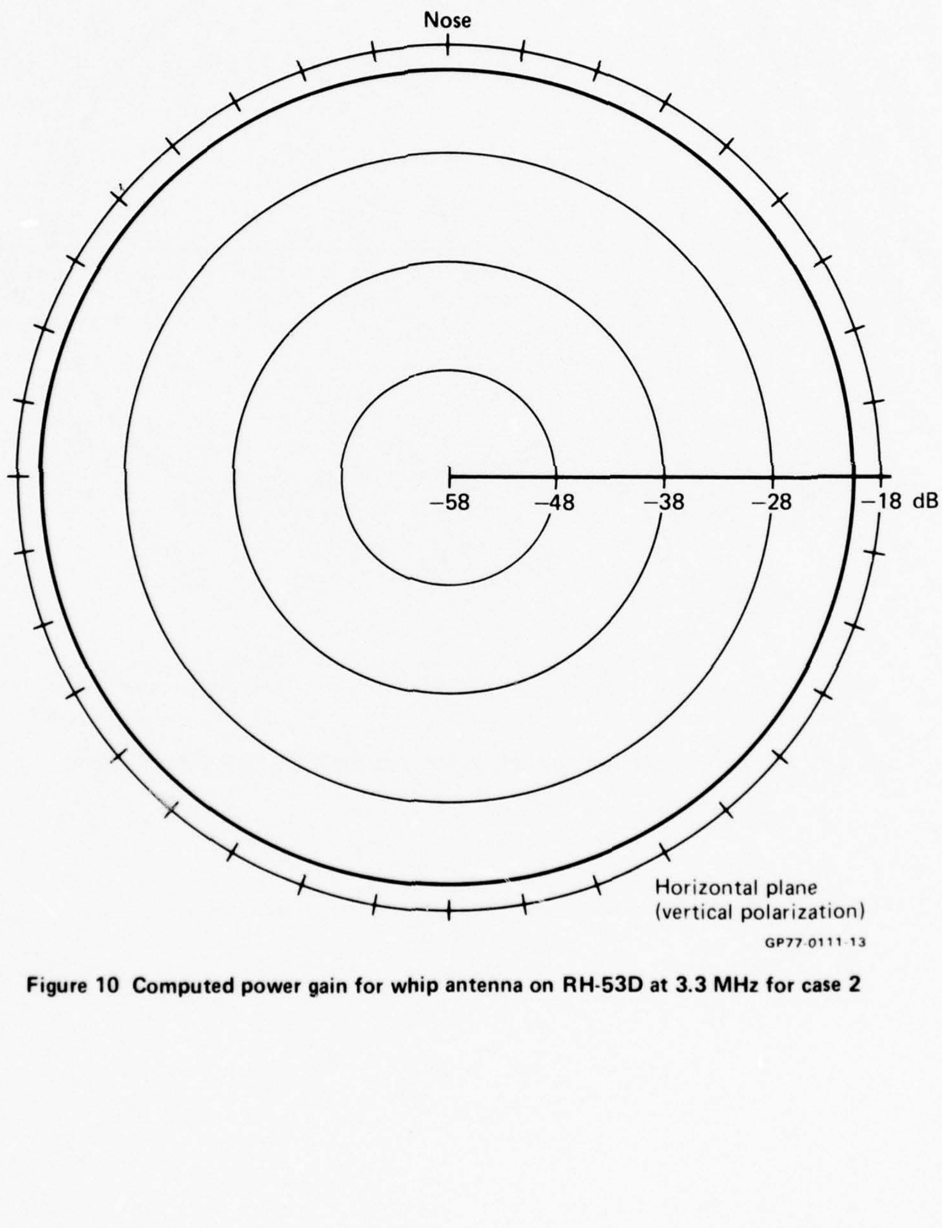

Figure 10 Computed power gain for whip antenna on RH-53D at 3.3 MHz for case 2

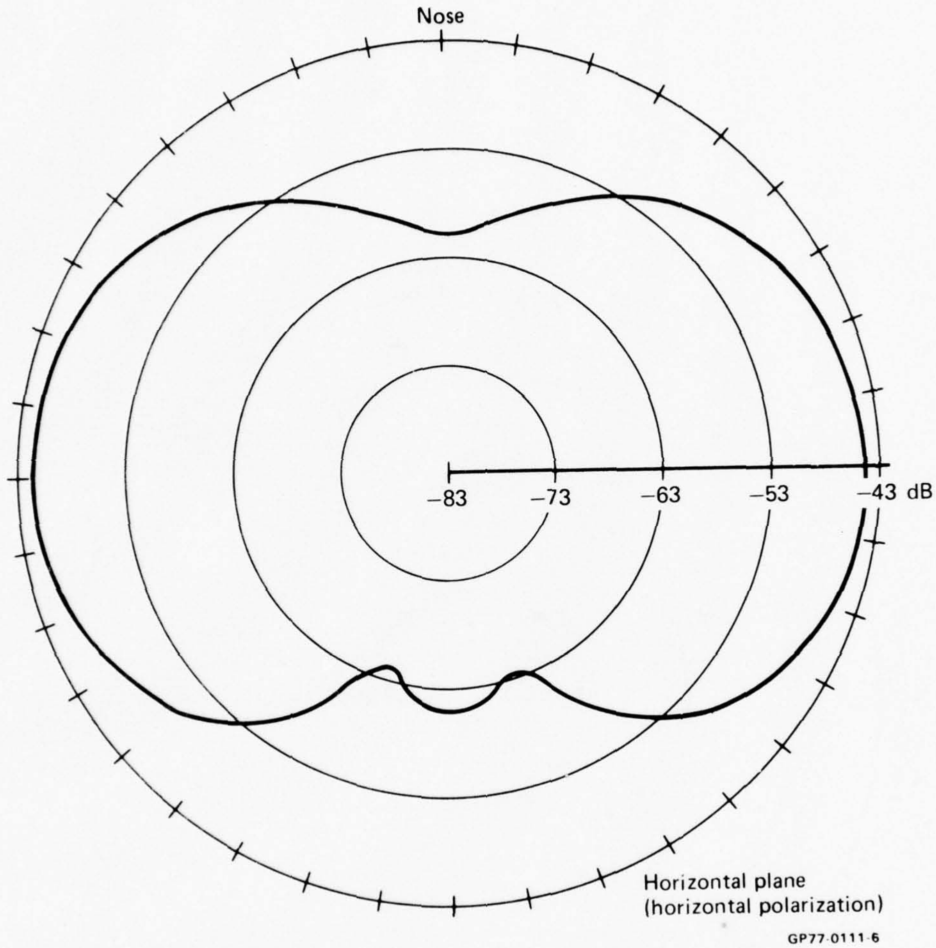

Figure 11 Computed power gain for whip antenna on RH-53D at 3.3 MHz for case 2

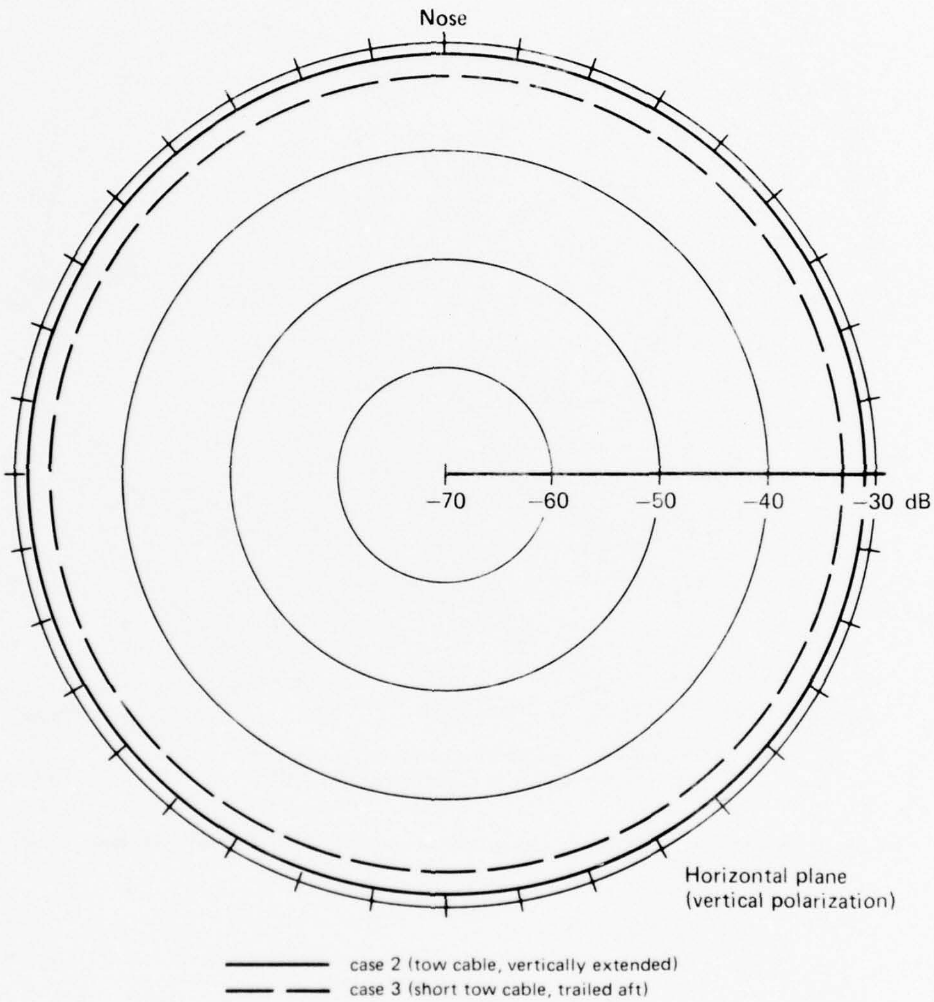

Figure 12 Computed power gain for whip antenna on RH-53D at 1.6 MHz for cases 2 and 3

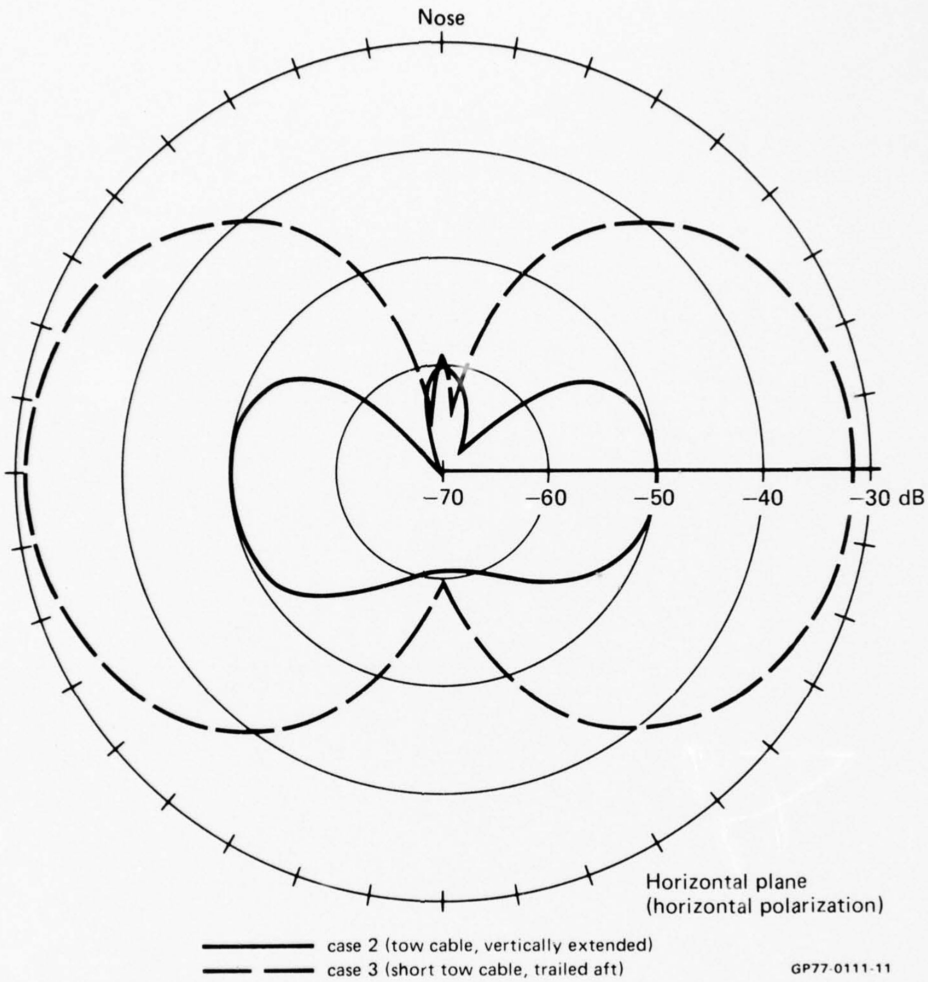

Figure 13 Computed power gain for whip antenna on RH-53D at 1.6 MHz for cases 2 and 3

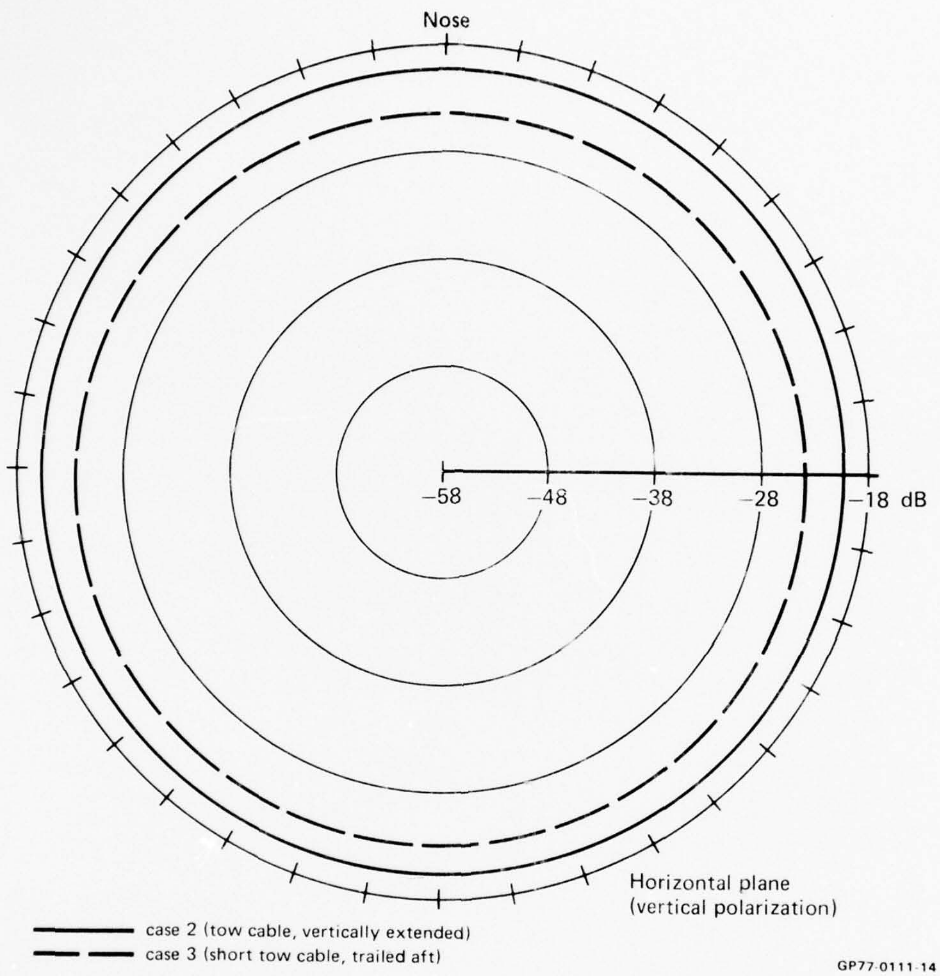

Figure 14 Computed power gain for whip antenna on RH-53D at 3.3 MHz for cases 2 and 3

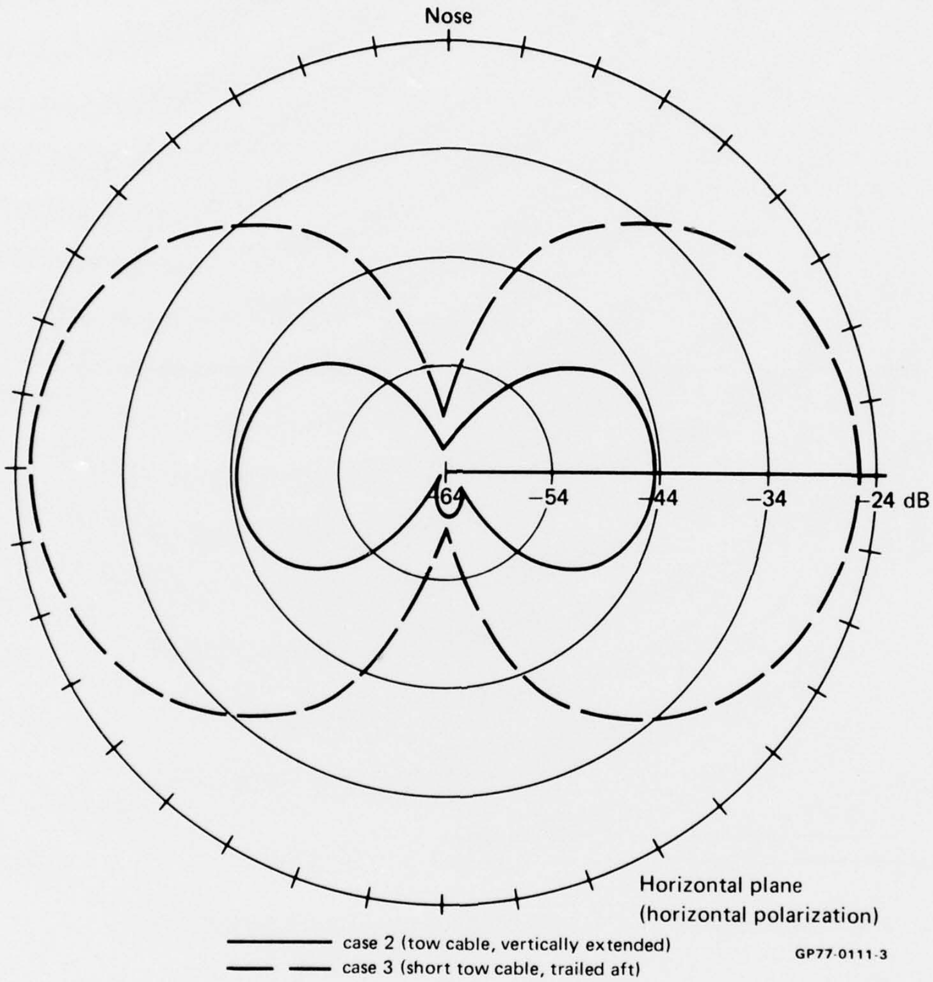

Figure 15 Computed power gain for whip antenna on RH-53D at 3.3 MHz for cases 2 and 3

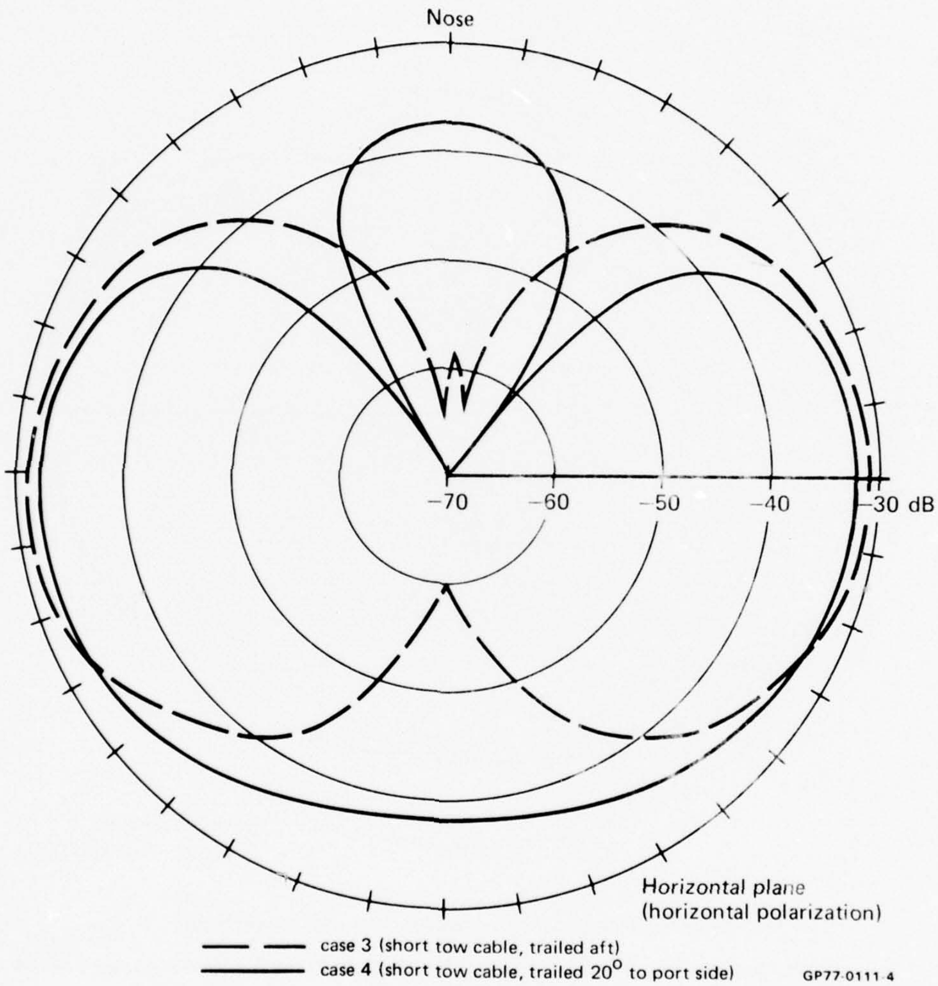

Figure 16 Computed power gain for whip antenna on RH-53D at 1.6 MHz for cases 3 and 4

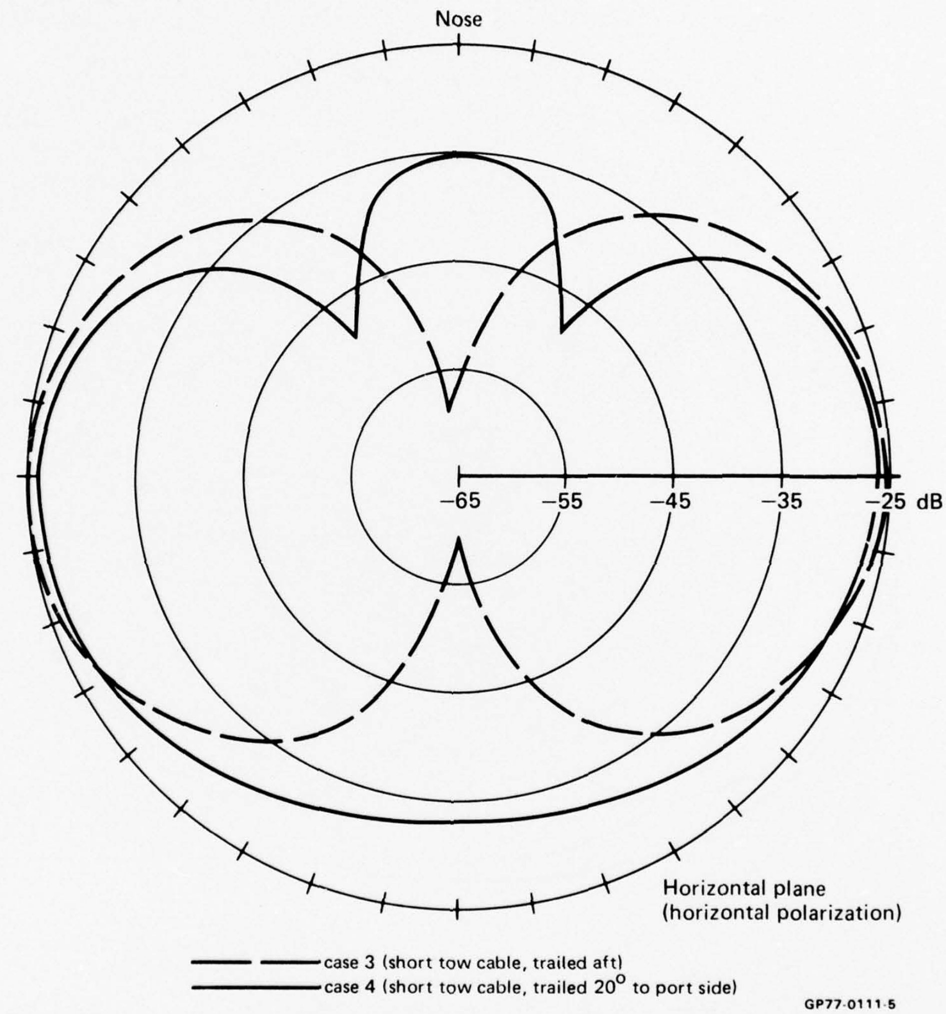

Figure 17 Computed power gain for whip antenna on RH-53D at 3.3 MHz for cases 3 and 4

symmetry in the radiating or receiving structure which, of course, is absent in this case. Again, in this configuration the phase shifts for the antenna patterns are significant. (see Figures 4 and 7, Case 4)

Case 5: Long tow cable, trailed aft.

For this case, a tow cable of 137 m (450 ft) length was used and trailed behind the aircraft, forming an angle of 13 deg. with the sea surface. This configuration is the usual tow mode for the Mark 105 platform. The power gain patterns for vertical and horizontal polarization and the phase changes for the vertical polarization at 1.6 MHz are shown in Figures 18-20. The increased lobe structure in the patterns reflects the fact that in this case the electrical length of the composite aircraft-tow cable configuration is comparable to a wavelength. As seen in Figure 20, the phase of the gain pattern (for vertical polarization) crosses the zero axis, corresponding to a power gain minimum at $\theta = 90$ deg. The maximum phase swing from the nose of the aircraft to the tail is considerable, namely 420 deg. The corresponding results at 3.3 MHz are shown in Figures 21-23. At this frequency, the composite structure is approximately two wavelengths long electrically, and hence additional lobes in the gain and corresponding zero crossings in the phase appear.

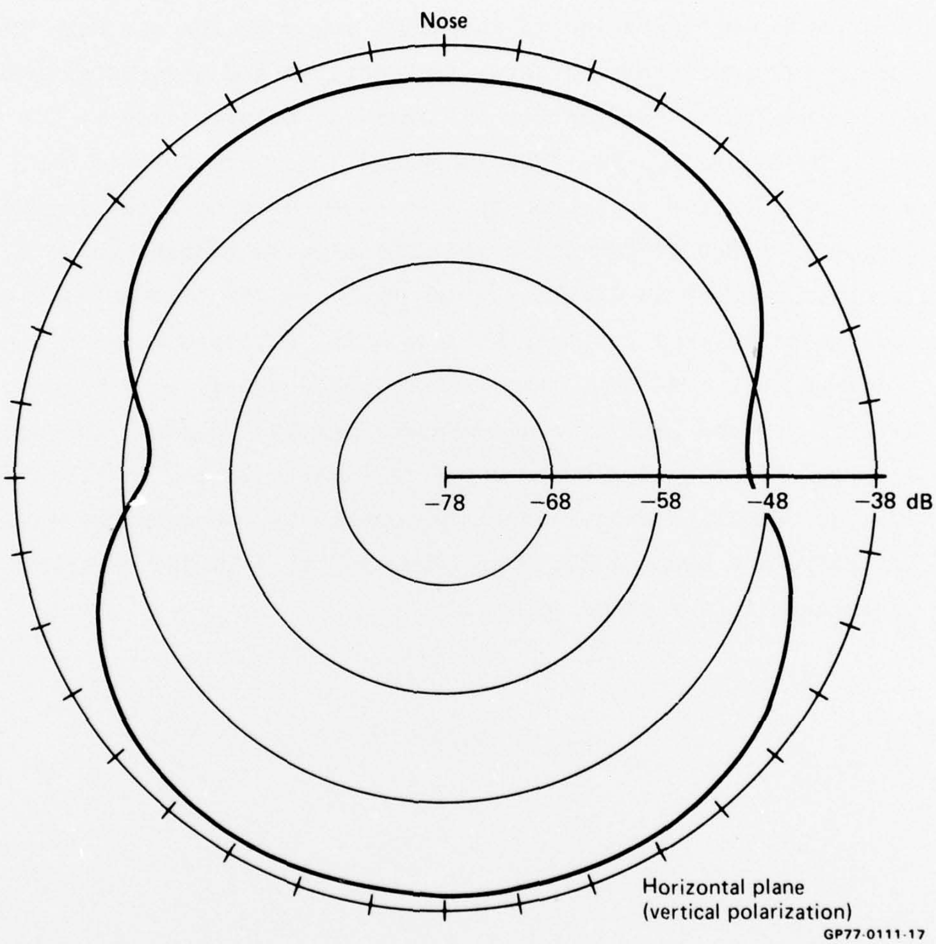

Figure 18 Computed power gain for whip antenna on RH-53D at 1.6 MHz for case 5

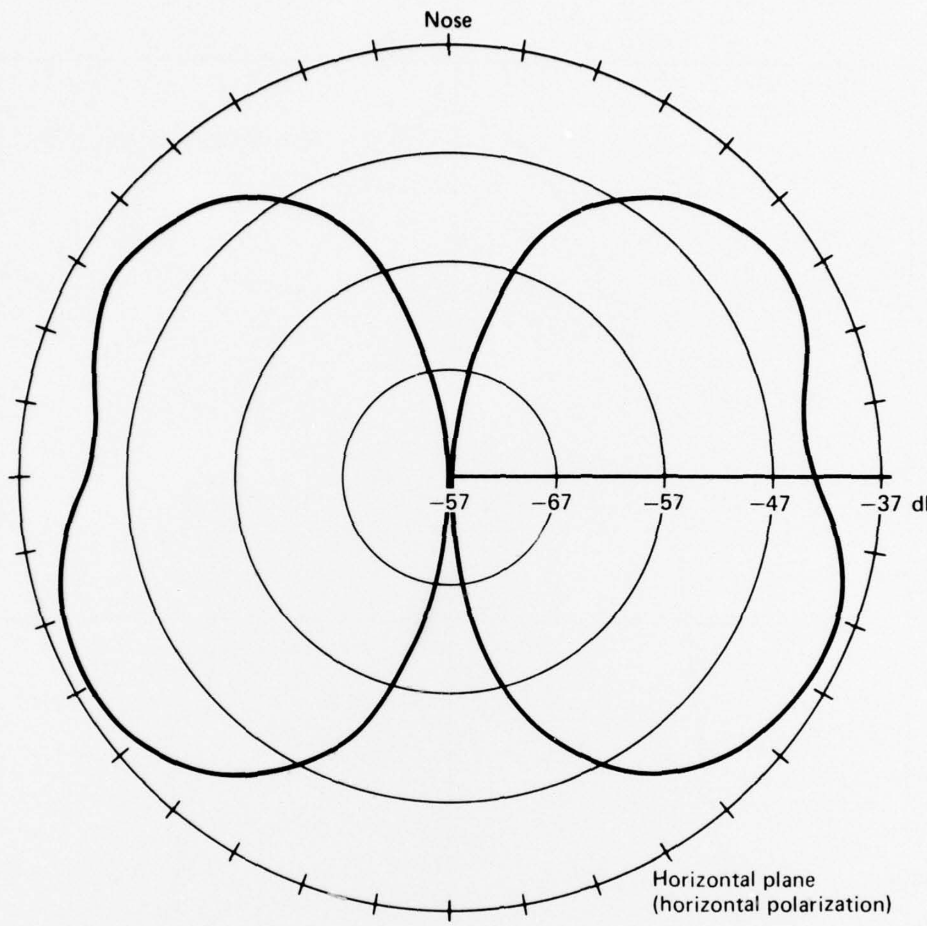

Figure 19 Computed power gain for whip antenna on RH-53D at 1.6 MHz for case 5

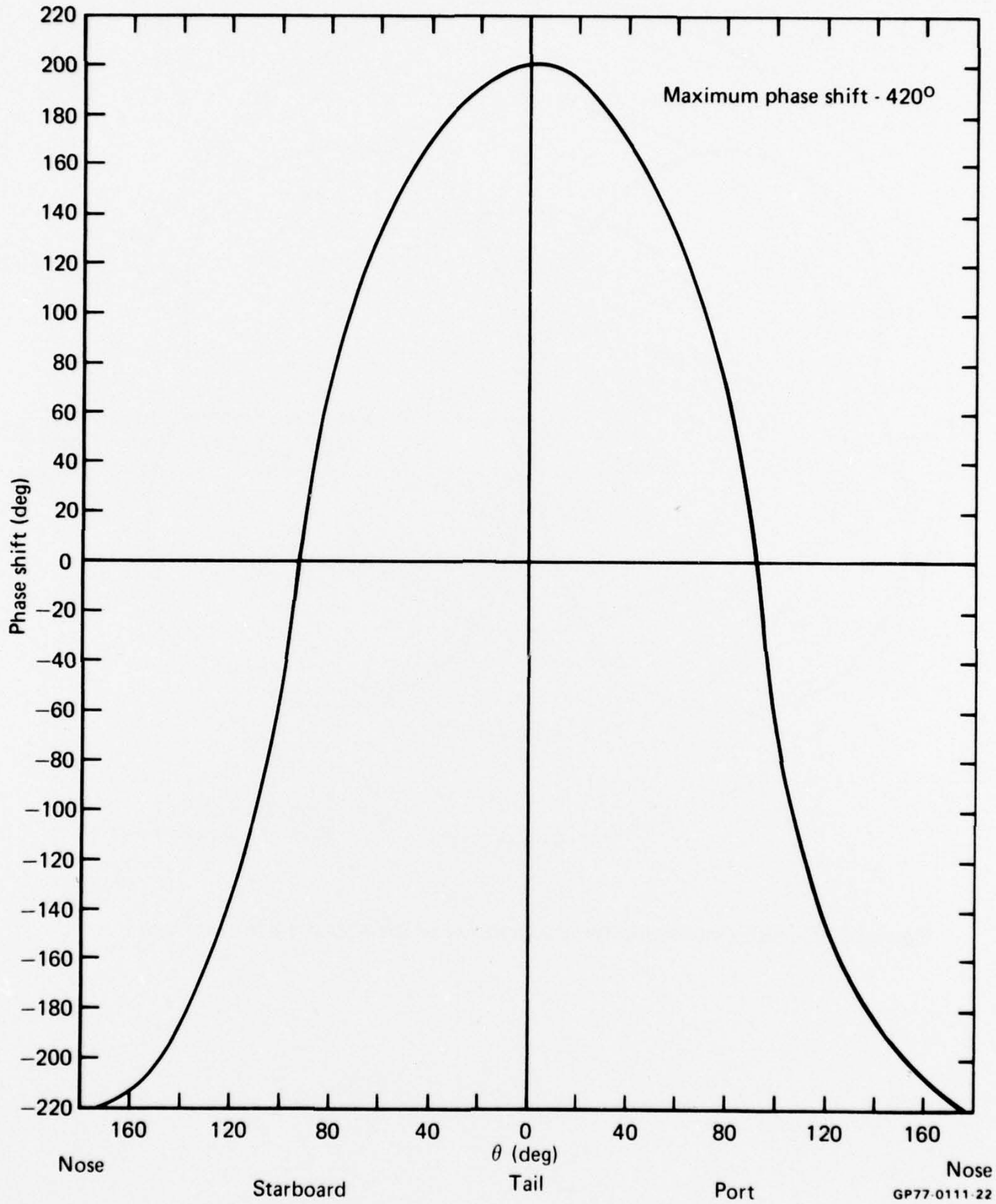

Figure 20 Phase variation for case 5 at 1.6 MHz (vertical polarization)

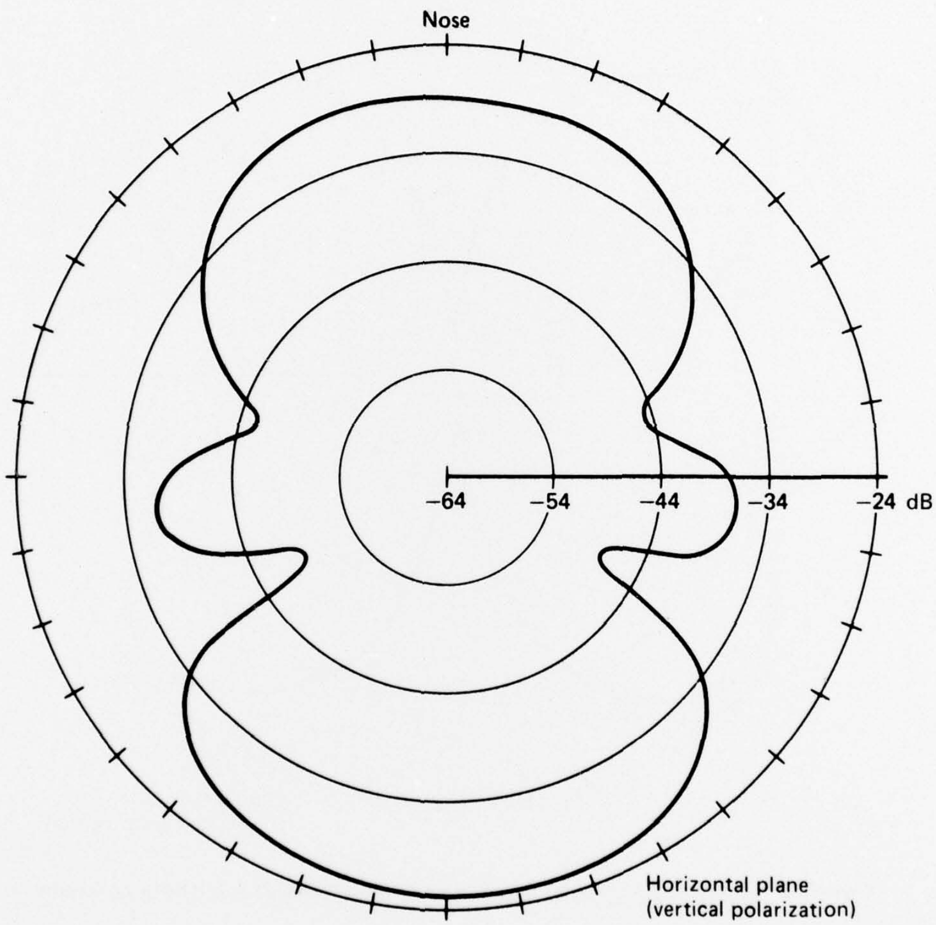

Figure 21 Computed power gain for whip antenna on RH-53D at 3.3 MHz for case 5

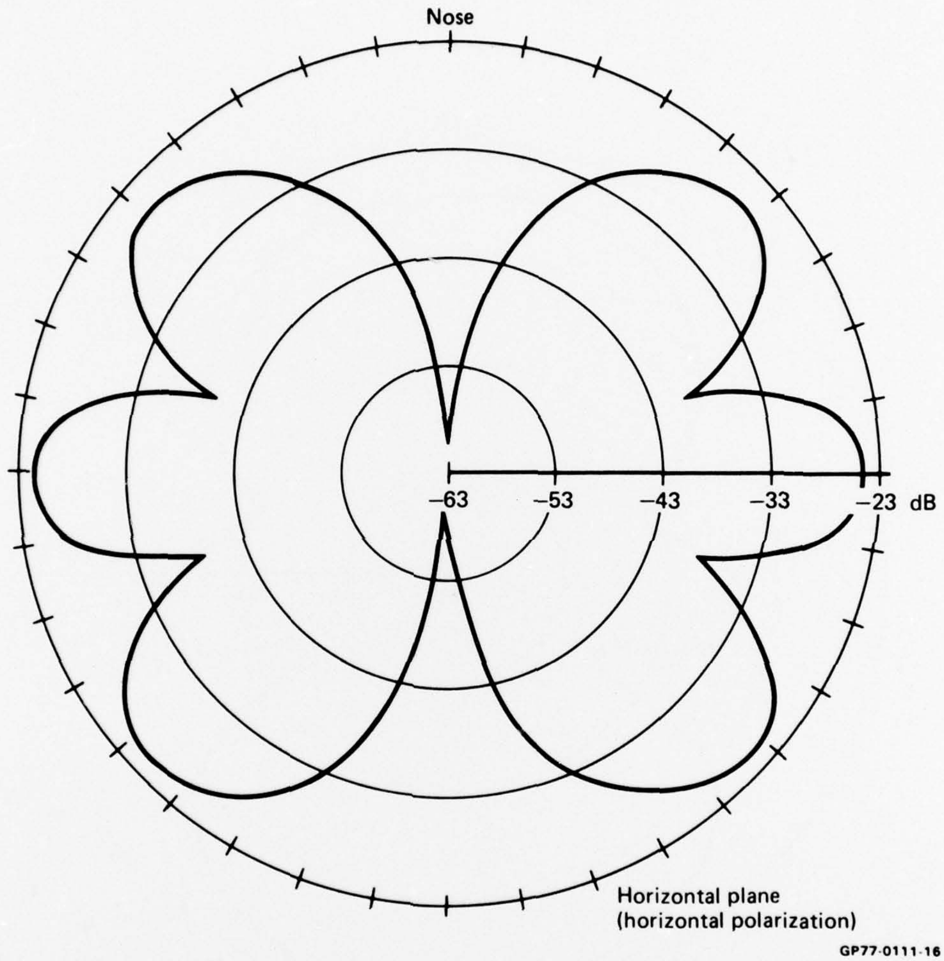

Figure 22 Computed power gain for whip antenna on RH-53D at 3.3 MHz for case 5

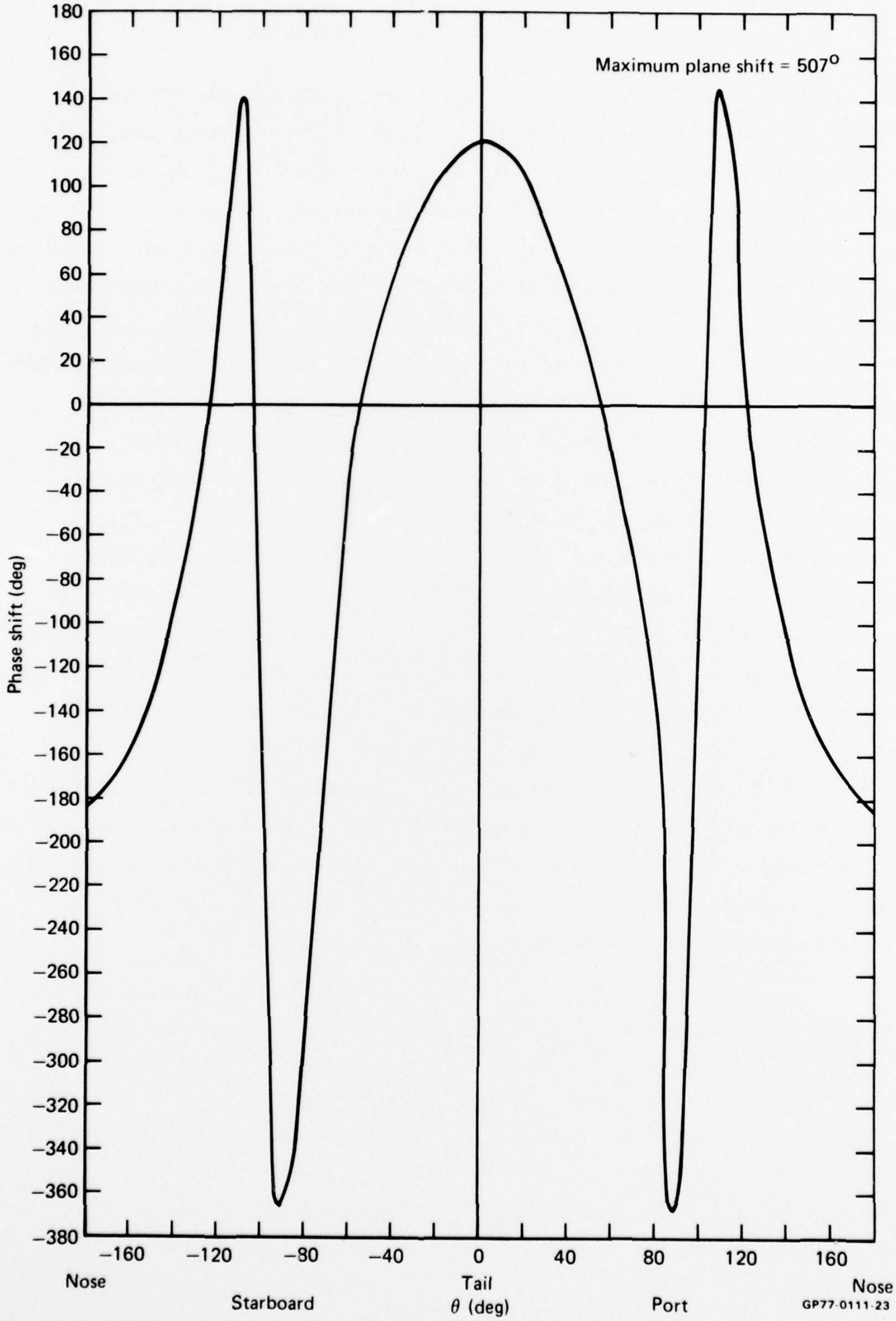

Figure 23 Phase variation for case 5 at 3.3 MHz (vertical polarization)

4. IMPLICATION OF PHASE VARIATIONS

As was noted above there is nonisotropy in the phase for the receiving antenna system aboard the helicopter when various tow cable configurations are considered. (see Figures 4 and 7) In the usual Raydist installation an isotropic receiving antenna is used so that phase differences detected by the phase comparators aboard the vessel or aircraft can be related uniquely to a given position in the hyperbolic coordinate system generated by the Raydist system. Phase anisotropies introduced by the receiving antenna system, can lead to incorrect interpretation of the detected phase differences and result in erroneous navigational data. This effect can be demonstrated as follows.

The standard arrangement of a four station Raydist transmitter system for hyperbolic mode operation is shown in Figure 24. The cw transmitters are denoted by "1" and "2"; the corresponding transmitters operating on the lower side band (LSB) and upper side band (USB) frequencies are "A" and "B", respectively. Typical frequencies corresponding to "1" and "2" are 3307.420 and 3307.570 kHz, and the corresponding LSB and USB frequencies of "A" and "B" are 1653.155 and 1654.28 kHz, respectively. (In the foregoing calculations nominal frequencies of 1.6 and 3.3 MHz were used to demonstrate the overall radiation characteristics of the whip antenna.) If the aircraft is assumed to be located at point H (Figure 24), the output of the two phase comparators aboard the aircraft, detecting the phase difference between the two pairs of cw and SSB transmitters, may be expressed as:

$$\psi_{1-A} = \phi_{1-A} + \Delta\phi(\theta_{AH}, \theta_{1H})$$

$$\psi_{2-B} = \phi_{2-B} + \Delta\phi(\theta_{BH}, \theta_{2H})$$

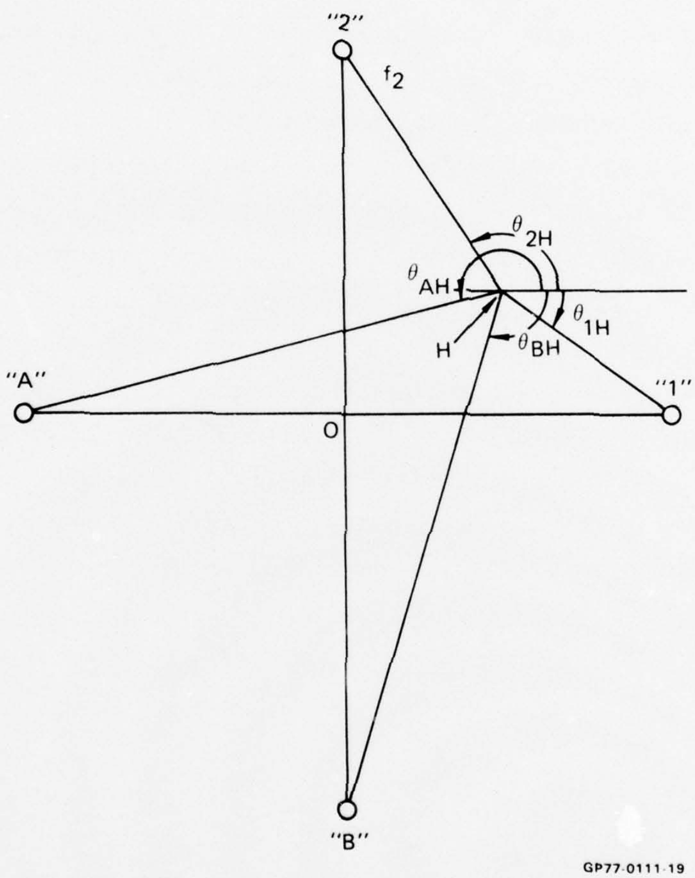

Figure 24 Four-station Raydist "T" system

where ϕ_{1-A} and ϕ_{2-B} are the phase differences measured at H between a pair of cw and SSB signals, assuming an isotropic receiving antenna on the aircraft. Note ϕ_{1-A} and ϕ_{2-B} are functions of the distance of the helicopter from the Raydist transmitters, whereas $\Delta\phi$ is a function of the difference of phase variation in the receiving antenna at the cw and the SSB frequencies (3.3 and 1.6 MHz in the present calculations). The term $\Delta\phi$ is also a function of the direction angle between the helicopter and the Raydist transmitters. The phase shift difference in vertical polarization for the five cases considered in this study are summarized in Figure 25. All results are initialized to zero phase difference at the nose of the aircraft. As can be seen without the tow cable present, $\Delta\phi < 20$ deg. and very slowly varying with the orientation of the aircraft. Thus in this case, the phase comparators aboard the aircraft respond effectively to distances from the Raydist transmitters alone since $\psi_{1-A} \sim \phi_{1-A}$ and $\psi_{2-B} \sim \phi_{2-B}$. However, as seen in Figure 25, for the other cases $\Delta\phi$ undergoes significant variation. These become particularly pronounced for the long tow cable (Case 5) and thus the phase detected aboard the aircraft contains the tow cable effects. In principle, if the helicopter is in a hover mode over a fixed point and turning, the phase variation in the receiving antenna pattern may produce outputs on the phase comparators similar to ones produced by lateral flight (and lane changes).

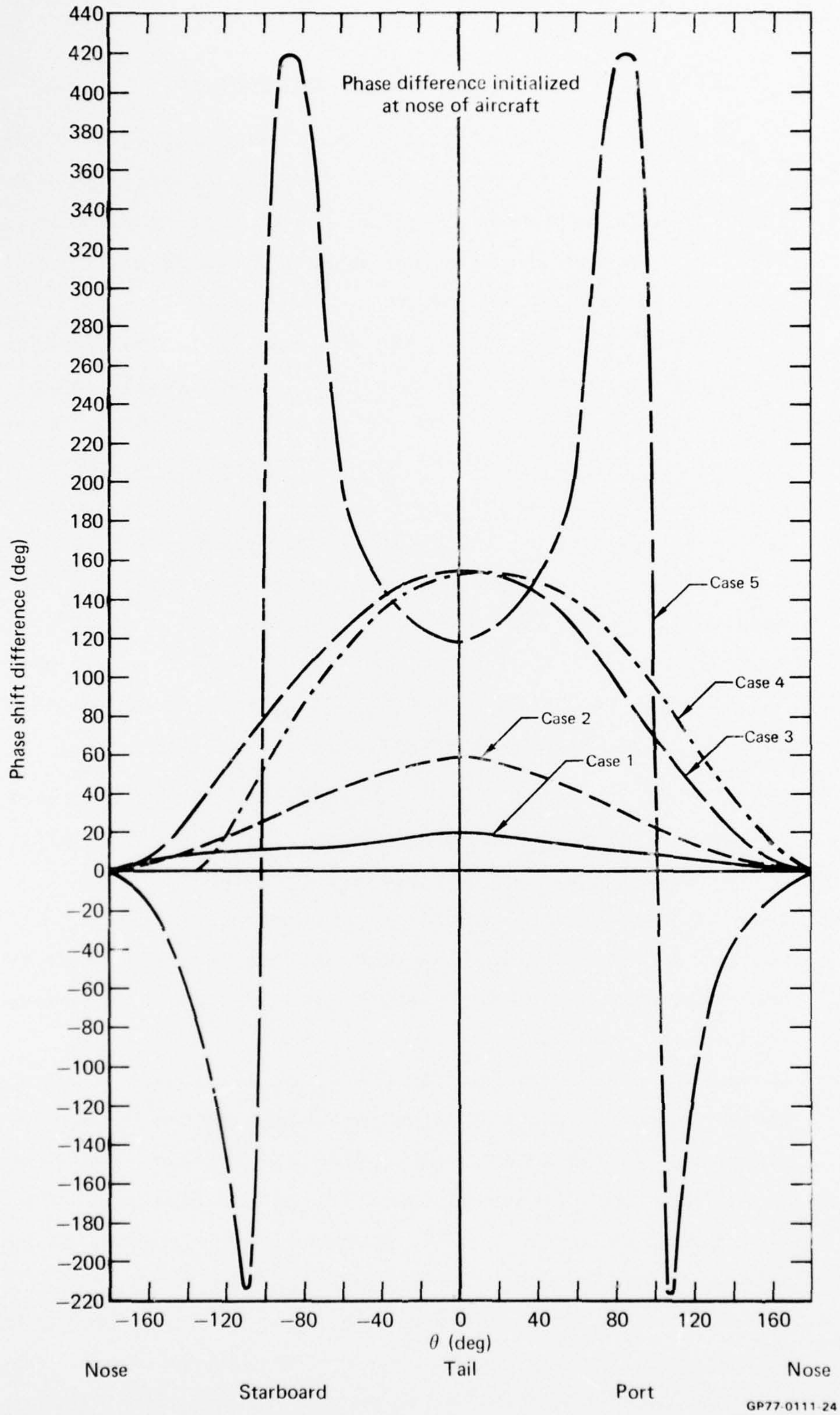

Figure 25 Phase shift difference for vertical polarization

5. CONCLUSIONS AND RECOMMENDATIONS

1) The computer calculations show that the bottom mounted whip antenna (modified retractable hf type) on the RH-53D helicopter is effectively isotropic in both magnitude and phase in the absence of a tow cable. In this configuration this antenna appears to be an effective receiving element for Raydist navigation.
2) In the presence of a tow cable, the analysis indicates considerable phase anisotropy in the radiation pattern. Horizontally and vertically polarized currents appear to be induced on the fuselage by the incident signals from the Raydist transmitters. These currents couple to both the receiving antenna and the tow cable, with the latter acting as a competing receiving system. The phase (and power gain) anisotropy appears to be pre-dominant when the RH-53D operates in the usual tow mode with a cable of 137 m (450 ft) length.
3) It appears that an AMCM platform and tow cable such as the Mark 103 that is strongly coupled to the sea will accentuate the phase variations in the receiving antenna system.

To improve the receiving system on the RH-53D for Raydist navigation, a two-pronged apprach combining experimental as well as analytical techniques is recommended. Specifically we recommend:

1) Computer calculations should be performed for different antenna configurations, in which the fuselage coupling and currents are parametrically varied for optimum isotropic radiation characteristics.
2) An experimental investigation should be undertaken to identify modifications to the present whip antenna system to improve the efficiency of the antenna (by tuning and impedance matching) and to minimize the deleterious coupling to the fuselage. The possibility of using two whip antennas properly tuned to the principal Raydist frequencies should be considered.
3) Optimization studies should be performed to determine the best antenna location for the most promising antenna configuration obtained from the experimental and analytical effort above.

4) In case the modifications of the whip antenna do not yield sufficient satisfactory improvements in performance as determined by full scale tests on the RH-53D helicopter operating with the Mark 103 AMCM system, a new antenna configuration minimizing the interaction with the fuselage currents should be considered.

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